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# LTCC - The Compelling Alternative

**The increasing number of electronic components and the steadily growing demand for packing density make it necessary to consider new possibilities in packaging. One of the technologies that is most interesting and significant for the future is LTCC (low temperature cofired ceramic), low sintering ceramic. There follows a survey of the current state of the art and the continuing potential of this technology: The technical department Electroceramics of IBM Deutschland Produktion GmbH regards this technology as a business field promising success. In this context, materials development plays a decisive role. Product department Dickfilm (Thick Film) of W. C. Heraeus GmbH is currently working on a further optimization of its existing LTCC systems. The principal aim is to be able to offer on the market a generally qualified material system.**

The steadily rising integration density in the semiconductor industry also requires an improved efficiency in packaging. The growth in contact density, the higher power loss of the chips and

the faster signal running times constitute an enormous challenge for a progressive, highly developed multi-layer ceramic technology. Rapid signal pulses have to be sent through the connecting network without losing the superior efficiency of the semiconductor.

A reduction in component size and the integration of passive component parts are the current trends in the microelectronic industry. Only the new LTCC technology makes it possible to insert passive components such as resistors and capacitors into the multi-layer package of the first wiring planes.

In general, LTCC is a glass-ceramic mixture that is fired together with the metallization pastes (e.g. Ag, AgPd, Au) at a temperature below the melting point of the metals. Consequently, LTCC combines the possibilities of ceramics (HTCC) sintered at high temperatures in cofiring with those of thick film technology. In addition, this offers the advantage of lower sintering temperatures (<990 $^0$C) and lower dielectric constants. There are two basic types of LTCC systems in which one is made of a mixture of glass and ceramic, and the other a crystallizing glass ceramic.

IBM Produktion GmbH, a 100% subsidiary of IBM Germany GmbH, since 1976 manufactures multi-layer chip carriers at its works at Böblingen/Sindelfingen. Since the beginning of this period, more than 3 million single and multichip modules have been produced, however, solely for IBM's own computer production. Besides the production of HTCC substrates, a new product line was set up in 1986 for an IBM-specific glass ceramic, which produced exclusively substrates for IBM large computer ~~[mainframe]~~ systems. The production of these components ended in 1994 because of a drastic collapse in the large computer market and the resulting sinking demand for these glass ceramic substrates.

Manufacturing was consolidated, and the parts were now manufactured completely in the USA.

Since 1992 IBM Produktion GmbH is offering its HTCC multi-layer technology on the European market. Substrates for use in data processing as well as in aeronautics and space travel technology are delivered to French, Italian and German customers. In 1993, in order to broaden the production spectrum, a new technology was introduced, namely a commercial LTCC system. In this context, it is planned that the manufacturing capacity in this technology will be expanded in the coming years to accomodate very high volumes.

At the present time, there is a multiplicity of applications for HTCC, and quite especially for LTCC substrates, which may expand drastically in the near future. Strong expansion is expected in particular in the field of automobile technology with its steadily climbing number of electronic components. Especially in the aggressive environment of an engine compartment having oily, damp, partly salt-containing atmospheres, having to deal with extreme vibrations and high mechanical and thermal loads, the ceramic solution is far superior to other technologies. This also applies to other applications in which there is a requirement for reliability and stability. The development in the LTCC sector takes into account the advances in the automobile electronics industry which shows, for example, in engine management, antilock systems, transmission control, injection systems, air bag release systems, sensors, etc. The reliability requirements are satisfied more effectively by LTCC.

LTCC makes possible manufacturing multi-chip, multi-layer modules having a very high integration density. This technology finds applications in the telecommunications field, data processing and in the automobile industry as a self-contained packaging concept.

The possibility of inserting outlying printed conductors into the multi-layer ceramics will additionally lead to further development of hybrid circuits. In addition to that, LTCC demonstrates more favorable high frequency properties, and offers the possibility of inserting non-active components. (Figure 1).

World-wide competition is exercising ever increasing pressure to offer cost-effective solutions. This applies especially to packaging in automobile technology with all its demands with regard to safety and reliability. Compared to organic packaging, in ceramic packaging, the positive environmental aspect should be taken into consideration.

The current development tasks relate to the following points:

- > energy saving (e.g. by low temperature sintering),
- > savings in process materials (e.g. sintering in air instead of oxygen),
- > economical use of noble metals,
- > introduction of non-toxic pastes,
- > observance of recycling concepts.

**Ceramic Packaging Solutions**

As is well known, hybrid multi-chip modules (MCM) are resistive and reliable components for electronic applications. Especially in aggressive environments, these have a clear advantage compared to the usual printed-circuit boards based on epoxide. Therefore, for such applications, market share will grow steadily. Developments in the automobile technology, where hybrid technology is dominant at this time, moves very fast in the direction of increasing complexity and integration. The strategy of leading automobile manufacturers tends to the idea of bringing the electronic controls as close as possible to the functional units themselves. Because of that, the number of cable harnesses

can be greatly reduced, and thus costs can be significantly lowered. However, this means that many control units are located under the engine hood, and are consequently exposed to adverse environmental influences. In this environment, hybrid packaging based on LTCC is straight out the technology of choice. In the standard hybrid process, wiring is effected in a sequential series of printing, drying and firing of various paste types on a non-metallized ceramic substrate. This takes place in up to 30 working steps for a product having four thick film layers. On account of this complicated manufacturing sequence, this technology will come up against its upper limits for the above-named applications.

On the other hand, the LTCC multi-layer carrier offers the advantage that a greater part of the wiring is integrated into the ceramic substrate, and at the same time the hybrid thick film process can be applied. This represents an optimal combination of the advantages of both technologies. In addition, there is the possibility of integrating passive elements such as resistors and capacitors into the ceramics. This, above all, draws up an especially attractive outlook for future applications.

**LTCC Market Perspectives**

Definite signs can be recognized that the market demand for ceramic substrates in the near and long term will grow significantly, since ceramics additionally offer considerable advantages compared to printed-circuit boards based on epoxide. This applies, above all, to special requirements in automotive electronics.

LTCC is increasingly penetrating the hybrid market especially for high-end applications in the automobile and telecommunications fields, and in the coming year in Europe, a market volume of up

to 2 billion DM is expected.

**Material Properties and Requirements**

As seen from a theoretical point of view, a multiplicity of glass ceramics and glass/ceramic mixtures can be used to manufacture LTCC substrates. Nevertheless, only a few materials have the potential in them for being applied in industrial mass production. The chief requirements on a suitable LTCC system are:

> sintering temperature < 900 °C,
> possibility for cofiring (shrinking compatibility of metal and ceramic),
> no tendency to Ag migration/diffusion,
> low dielectric constant of the ceramic,
> good electrical parameters of the conducting phases,
> potential for buried, passive component elements,
> good mechanical properties,
> compatible cofiring and post-firing metallizations,
> dimensional stability during thick film firing processes,
> robust long-term behavior,
> manufacturability in existing production lines and
> competitive costs (compared to other technologies).

Upon consideration of all the above points, the number of LTCC systems that are possible and can be implemented under industrial conditions shrinks to a few.

The Electroceramics Department of IBM Deutschland Produktion GmbH is currently working closely together with Product Department Thick Films of of W. C. Heraeus GmbH. Their joint aim is to produce reliable and high quality LTCC substrates and to offer them in the marketplace.

**LTCC Substrate Manufacturing Process**

Figure 3 shows a schematic process flow of current IBM LTCC production.

The ceramic raw materials are worked up in a ball mill process together with organic binders and solvents. This is then poured in a tape-casting method to form foils 150 $\mu$m to 300 $\mu$m thick. Thereafter, the so-called "green sheets" are stamped out of this and are inspected both automatically and visually for defects.

After a certain aging period, which ensures a good dimensional stability, punching is carried out next, i.e. the stamping of the plate-throughs (vias) of the individual layers. This process is fully automated and includes a 100 % checking of the stamped holes.

Paste printing is usually done in two process steps. First the vias are filled with Ag paste in a masking printing method, and subsequently, the various printed conductor patterns are applied by silk screening. For the external layers, an Ag/Pd paste is used. All layers undergo a fully automatic inspection on the degree of fulness of the vias and printed conductor defects, and there follows appropriate culling or repair.

Thereafter, the various layers of a product are stacked automatically and are laminated at a temperature of 70 $^0$C under pressure. A sawing process is used to define the size of the laminate.

The sintering of LTCC parts is performed by IBM in air in a chamber ~~[box]~~ kiln, a special temperature profile having to be strictly maintained. After the outer dimensions and the dimensional accuracy of the metallization pattern (distortion)

are checked, the electrical test is done next. In this instance, all networks are tested for interruptions and short-circuits. Depending on the application, one may still perform a galvanic or currentless gilding of the outer contacting, or the parts are used directly as base substrates for subsequent thick film processes.

**LTCC Systems of Heraeus**

The inorganic base material of the tapes offered by Heraeus (Heratape CT 700) has been used in the form of thick film paste IP 9117 S as a multi-layer dielectric since the end of the eighties. At the usual temperatures of 850 to 870 °C, the dielectric inhibits silver migration, as described in the article *Zuverlässige Alternative (Reliable Alternatives)*, K. Deckelmann, H. G. Burckhardt, (special reprint from Productronic 1/2-1990).

The high softening temperature of the glass is seen to be the outstanding material property. During the sinter firing of the LTCC circuit, the glass recrystallizes and forms a stable system with the ceramic components which satisfies the requirement for as low a shrinkage as possible of the outer metallization and resistors in the subsequent post-firing.

Furthermore, the nearly complete recrystallization of the dielectric permits the double-sided post-firing in the continuous-heating furnace without there being any deformation **[sagging]** of the flat-lying circuits.

Distortion-free, plane LTCC circuits require an adaptation of the sintering characteristics of the inner metallization to the sintering characteristics of the dielectric.

With the aid of a test layer of IBM (Figure 3), which besides screening using an area coverage of > 85 % also has a highly dense via cluster having > 40,000 vias on an area of 4-1/2" x 4-1/2", the functionality of the Heraeus system could be demonstrated.

Short signal running times of an LTCC circuit require inner-lying printed conductors having as low a resistance as possible, which can only be implemented using pure silver pastes. The vertical connection of the printed conductors is made by vias which are also filled with Ag paste. In this system, AgPd and Au can also be used as outer metallization, besides Ag.

If, between the completion of the outer layers of an LTCC circuit and the bonding of active components there are longer periods having undefined layer conditions, highly alloyed Ag/Pd metallizations offer a reliable solution.

At the transition of Ag-filled vias to AgPd/Au, diffusion takes place (Kirkendall Effest), which, in the case of vias having a small diameters, may lead to metal consumption **[impoverishment]**. As a result, the connection may have an undesired high contact resistance. In the cofiring process there are two alternatives:

> the vias of the top layer are filled with a low-alloyed AgPd paste.
> a "via cap" is printed over the Ag-filled via. For this, there are available AgPd alloys having a low Pd content.

On account of the stepped alloy concentrations of the Pd, a reduction in the concentration gradient is achieved, and the diffusion speed is thereby reduced.

LTCC circuits, printed upon with post-firing resistors and

capacitors, or equipped with chip resistors and chip capacitors represent only the first step towards increasing the integration density. This reflects the current state of LTCC technology under production conditions. Figure 4 shows the example of a test layout which is used for a number of qualification steps.

A further reduction of the dimensions and manufacturing costs is only possible by the integration of buried components. W. C. Heraeus has made it its aim to offer the market by 1996 a materials system having buried resistors and capacitors.

## Summary

LTCC offers extremely favorable assumptions for future use in automotive electronics. The basic requirements on the next packaging generation, such as high integration density and reliability under extreme environmental conditions, can be satisfied. In addition, the unique possibility of embedding passive components into the multi-layer part opens attractive and very promising perspectives.

LTCC permits one to combine the advantages of a highly developed packaging technology with those of standard hybrid manufacturing. This will lead to an increase in technical efficiency, to greater integration and to a further reduction in component part size.

The shared aim of the Electroceramics Department of IBM Deutschland Produktion GmbH and Product Department Thick Film of W. C. Heraeus GmbH, within the scope of a close collaboration, is to drive forward the realization of a functional component by the end of 1995.

Additional information on LTCC substrate materials may be obtained from Heraeus using the code number or

Fax # 061 81/357 86.

Productronic 406

Information from IBM may be obtained using the code number or Fax # 070 31/12 69 06.

Productronic 407

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**Translation of the Figures**

**Figure 1: Packaging Solutions for Electronic Systems**

LTCC
buried components
fine line ?[1]
high packing density
?
?

MULTI-LAYER CERAMICS
high efficiency
wiring density
? chip
? grid array

HYBRID
? components
? resistors
?

EQUIPMENT
electronic applications
telecommunications applications

increased packing density
reduction in product size
improvement of high-frequency properties

[1]**Translator's Note: A ? Has been inserted to represent each illegible word.**

**Figure 2: Schematic LTCC Process Sequence**

| | |
|---|---|
| HERAEUS DIELECTRIC (powder) | working up pouring mass |
| | pouring ceramic foil |
| | stamping |
| | aging |
| | via stamping |
| | mask stamping |
| HERAEUS PASTES | stencil pressure (vias) |
| | silk-screen printing (printed conductors) |
| | inspection |
| | stacking/laminating |
| | sawing |
| | sintering |
| | dimensional measuring |
| | electrical test |
| | post-firing prints |
| | drying/firing |
| | laser trimming |
| | equipping/assembly |

Figure 3: LTCC Test Layer from IBM with > 85 % Area Coverage at Screening and Open Via Cluster Having > 40,000 Vias, Test Layout from W. C. Heraeus

Figure 4: LTCC Test Layout Having 101.6 mm x 101.6 mm. 6 Layers, 0.75 mm Thickness, 16 Chip Sizes, Silver Metallization and Barium Alumosilicate [Aluminosilicate?] as Dielectric